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13. ABSTRACT (Maximum 200 words)

The primary purpose of our MURI project was to explore and quantify the basic scientific and mathematical phenomena which can be exploited to detect, locate, and identify landmines, buried or on the earth's surface. Basic research projects was aimed at supporting the Army missions of airborne screening for minefields, forward-looking mine detection from vehicle-mounted systems, and mine detection with hand-held systems. Basic research projects were undertaken in the areas of signal processing and detection algorithms for Ground Penetrating Radar (GPR), multi-algorithm and multi-sensor fusion, image processing and detection algorithms for lightweight airborne mine detection, concepts for designing and fielding new GPR based mine detection systems, human in the loop analysis of operator performance and virtual reality systems for training for hand-held mine detection, detection of EMI from printed circuit boards in land mines, and development of new sensing strategies based on chemical vapor sniffing. Good improvements in probabilities of detection and false alarm rates have been achieved in the algorithm work. Significant improvement in training effectiveness was demonstrated with virtual reality training. Very sensitive chemical detectors have been evaluated in laboratory settings.

14. SUBJECT TERMS
landmines, humanitarian demining, chemical vapor sensing, ground penetrating radar, hidden Markov models, sensor fusion, human operator, virtual reality, human-machine interface, hand-held landmine detection, airborne minefield detection

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MULTIDISCIPLINARY RESEARCH IN MINE DETECTION AND NEUTRALIZATION SYSTEMS: MISSOURI-LED MURI

Final Progress Report

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EXECUTIVE SUMMARY

The primary purpose of this Missouri-led Multi-University Research Initiative (MURI) was to explore and quantify the basic scientific and mathematical phenomena which can be exploited to detect, locate, and identify landmines, buried or on the earth's surface. The MURI team was lead by University of Missouri-Rolla (UMR) and involved faculty and students from University of Missouri-Columbia (UMC), Kansas University (KU), University of Texas at Arlington (UTA) and Carnegie Melon University (CMU). Basic research projects was aimed at supporting the Army missions of airborne screening for minefields, forward-looking mine detection from vehicle-mounted systems, and mine detection with hand-held systems. Over the five years of the contract, various technologies, algorithms and systems were research and developed. Good improvements in probabilities of detection and false alarm rates were achieved in the algorithm work. Significant improvement in training effectiveness was demonstrated with virtual reality training. Very sensitive chemical detectors was evaluated in laboratory settings. This report provides a brief summary of important results. A list of publications and reports published under the grant is provided along with participating scientific personnel.

1. STATEMENT OF THE PROBLEM

The primary aim of this multi-university multi-disciplinary research project was to explore and quantify the basic scientific and mathematical phenomena which can be exploited to detect, locate, and identify landmines, buried or on the earth's surface. Basic research projects was aimed at supporting the Army missions of airborne screening for minefields, forward-looking mine detection from vehicle-mounted systems, and mine detection with hand-held systems. Basic research projects were undertaken in the following areas:

- Signal processing and detection algorithms for Ground Penetrating Radar (GPR),
- Multi-algorithm and multi-sensor fusion,
- Image processing and detection algorithms for airborne mine and minefield detection,
- Concepts for designing and fielding new GPR based mine detection systems,
- Human in the loop analysis of operator performance for hand-held mine detection,
- Virtual reality systems for training of operators for hand-held mine detection,
- Detection of EMI from printed circuit boards in land mines,
- Use of waterjets in mine detection and neutralization,
- Development of new sensing strategies based on chemical vapor sniffing,
- New radar systems for detection of symmetrical buried objects.

2. SUMMARY OF IMPORTANT RESULTS

2.1 Vehicle Mounted Ground Penetrating Radar (GPR) Detection Algorithms [1-3]

Engineers and scientists at the University of Missouri developed new methods for analyzing Ground Penetrating Radar (GPR) data for detecting landmines. Statistical and fuzzy models are used to perform discrimination between mines and non-mines. Fuzzy set based algorithms were developed and demonstrated in the laboratory. Based on their success, they were transitioned to a prototype vehicle mounted mine detection system and blind tested in real-time in the field on data collected at multiple geographical locations over thousands of square meters. The methods achieved excellent performance as described in the report on the advanced technology demonstration. New methods based on hidden Markov models were also developed. These methods made use of statistical information contained in large numbers of samples to model the variation in mine and background signals. In addition, methods based on the combination of mathematical morphology and neural networks were investigated and tested in the laboratory, yielding results of well over 90% detection at a false alarm rate of 0.02 false alarms per square meter.

2.2. Fusion of Multi-Source Information [4-6]

Basic research was performed in the area of multi-sensor and multi-algorithm fusion. Choquet integrals, which are nonlinear integrals utilizing nonlinear measures, were investigated and generalized using mathematical morphology in one case and using linguistic vectors in another. Theoretical development combined with extensive laboratory experiments on real data resulted in dramatic decreases in false alarm rates, sometimes as much as 50% in the false alarm rate while maintaining high probabilities of detection.

Methods were developed to predict the behavior of detection systems if new sensors were introduced into a multi-sensor system. The methodology predicts changes in positional accuracy of multi-sensor systems as new sensors with given distributions of positional accuracy are introduced. In addition, estimates of the difference in separation between confidence outputs for mines and non-mines can be computed. The goal of this research is to save costs by simulating multi-sensor systems without having to actually build them. The techniques rely on the use of a mathematical representation of fusion methodology using the Choquet integral that is very general, encompassing a wide variety of commonly used fusion algorithms.

2.3. Region Processing for Hand-Held Ground Penetrating Radar (GPR) Landmine Detection [7-8]

Scientists and engineers at the University of Missouri developed methods for incorporating spatial information into hand-held GPR-based mine detection systems. Typically, it is very difficult to incorporate such information because the systems are wielded by humans, rather than by machines. There is no positional information necessary. The approach uses auto-correlation analysis to estimate the spatial consistency. False alarm rates were reduced from 38% to 9% at 100% detection on an outdoor test site containing anti-personnel mines and discrete clutter objects.

Spatially distributed features based on weighted density distribution functions have been applied to sequences of metal detector outputs in hand-held units to the detection of land mines. The spatially distributed features involve correlating sequences of MD energy values with six weighted density distribution functions. These features have been evaluated using a standard back propagation neural network on real data sets acquired from multiple test sites. These data sets contain more than 2,300 mine encounters of different size, shape, content and metal composition that are measured under different soil conditions. Receiver operating characteristic (ROC) curves have been used for algorithm evaluation, showing the probability of detection versus the false alarm rate (per m2). Results from applying weighted density distribution basis functions for generating metal detector features have shown substantial improvement over a baseline maximum approach. The weighted density distribution function features have been extended to fusion with existing linear prediction detector features for ground penetrating radar within the hand-held units. Results using the data sets above have shown sensor fusion provides improvement over the ground penetrating radar or metal detector used in isolation.

2.4. Airborne Mine and Minefield Detection [9-11]

Image analysis techniques have been developed to detect surface land mines in broadband Multispectral Medium-Wave Infrared (MWIR) images from the Lightweight Airborne Minefield Detection – Interim (LAMD-I) program. Algorithms have been developed to improve anomaly detection, false alarm mitigation, and minefield detection. The gray-scale moment based features were shown to significantly reduce false alarm with minimal reduction in probability of detection and limited computational penalty. Circular harmonics transform-based approach has been investigated for isolating land mines. Significant improvement in mine detection ROC performance has been demonstrated. The countermine division of Night Vision and Electronics Systems Directorate under the LAMD-I program is funding follow-on work in airborne mine and minefield detection.

A background literature and information source review has been conducted for the determination of different minefield types and the associated mine types, densities and layouts. A listing of the references compiled for minefield description is located at: http://www.isc.umr.edu/projects/ReferencesMineFieldDescription.htm.

2.5. Energy Coupling with Landmine Electronics [12-14]

Researchers at the University of Missouri-Rolla have identified and quantified new physics associated with energy coupling from and to electronics on printed circuit boards. In addition to identifying and demonstrating two new energy coupling paths that result from layout parasitics, means of anticipating and estimating the coupling from closed-form expressions have been developed. New measurement techniques were also developed to demonstrate the physics and validate the theory.

A powerful CAD tool has also been developed based on a first-principles Maxwell's equation formulation. The CAD tool models the printed circuit geometry from first principles, and then extracts an equivalent circuit model for the parasitic energy coupling path that is compatible with general SPICE circuit simulators. This allows for evaluation of electromagnetic interference coupling and radiation from the electronics, as well as the electrical noise that can be induced in the circuit from an external source. The results of this project are being used in follow-on work with the Navy for developing a detection and neutralization system for electronics used to detonate explosives.

2.6. Man-in-the-Loop Training Tools [15-17]

Scientists and engineers at Carnegie Mellon University has been looking at the man-in-the-loop issues for hand-held landmine detectors. Field test results showed that in addition to better hardware and software for new detectors, new training tools are desperately needed to train the operators of these detectors. After reviewing the current training method, and observing many hours of training, they have developed two new tools. The first tool is a multipurpose real-time 3-D tracking system that can be used to provide real-time feedback during training, and to analyze the performance of the operator and the detector independently from each other. This tool provides the trainer and the trainee all the relevant parameters regarding the trainee's sweep technique in real-time. It can generate a warning if the trainee makes any mistake in his sweep technique, such as creating a gap in his coverage. In addition, the motion of the detector is completely captured and logged for later playback. This tool has been deployed successfully during training sessions for HSTAMIDS and PSS-12 detectors. Furthermore, the army is planning to officially incorporate this training tool for the HSTAMIDS. To facilitate this plan, Carnegie Mellon University has conducted a successful technology transfer to ETI, Inc. in Orlando, FL under the supervision of STRICOM. ETI is the entity that will produce the tracking units for the Army. The second tool that researchers at Carnegie Mellon University have developed is an extension of the multipurpose tracking system. They have developed a very flexible and realistic software-driven virtual minefield. The virtual minefield can be used to simulate both a real minefield and a real detector. Since it is software driven, no real mines need to be buried, and the composition and configuration of the mine field can be changed instantaneously. Furthermore, the virtual mine field can be deployed anywhere and anytime. It can be deployed indoor or outdoor. It can even be deployed on a ship deck. The beauty of the virtual minefield is that it is transparent to the trainee. As far as he is concern, he couldn't tell whether he is operating a real or simulated detector, or whether there is a real buried mine or a simulated one. This is possible because the software engine behind the virtual minefield computes the proper respond of the detector to the virtual mines based on their relative positions to each other. In the future, their relative orientations will also be taken into account. The virtual minefield is also very versatile since it can simulate various minefields conditions around the world. This capability is critical so we can train our soldiers to neutralize the threat of landmines at any region in the world.

2.7. Robotics System to Augment Handheld Mine Detection

The researchers at Carnegie Mellon University have also been looking at automation to reduce the risk of mine detection and increase the detection rate at the same time. They have developed a hybrid human-robotics system that can achieve both of these objectives. The key to success for this robotics system is properly mixing the autonomous capability of the robot and cognitive power of the human operator. The robot normally operates under a supervision of a human operator who is located at a safe distance from the minefield. It autonomously builds a precise terrain map of the minefield, and sweeps the detector at a preset height above the terrain. The operator can set this stand-off height, as well as the sweep rate and spacing. Since it is a mechanical device, it maintains the programmed sweep all the time, and it is not subject to fatigue, unlike a human operator. The robot can also be programmed to detect trip wires or other hazards. When the robot encounters a suspicious object, it notifies the operator that then has the option to override the automatic classification for that object. In addition, the operator can also take over the robot completely, and move the detector manually as if he is standing where the robot is located. By properly mixing automation and teleoperation, the sensory overload is reduced, and the human operator should be able to concentrate on the task that he is best at, which is discriminating the buried object. He no longer has to worry about sweeping his detector correctly, or watching for trip wires. Finally, since the operator is located at a safe distance away, the safety of the demining operation is also greatly increased.

2.8. The Use of Waterjets in Mine Detection and Neutralization [18-21]

The University of Missouri has developed new technology using high-pressure waterjet to penetrate the ground and produce ground motion and acoustic signals that allow the detection and discrimination of buried objects. The waterjet system can also be used to remove soil and ground cover from buried objects allowing visual inspection and neutralization. A demonstration hand-held system was built for NVESD Humanitarian Demining and was tested in July 2002 at Fort AP Hill.

In the early part of program, detection of metal and plastic mines using a heated waterjet was also investigated. The heat signature induced by the heated-waterjet was found to progress slowly to the surface (in mater of minutes) so that the technique was not thought to be practical for landmine detection. However direct measurement of the dissipation of the thermal signature seen through the borehole created by the waterjet was however shown to be a viable technology for landmine detection and discrimination.

2.9. TNT/DNT Chemical Detector [22-23]

A chemical sensor for detection of nitro aromatic explosive vapors trace levels has been developed. The sensor is based on dissociative electron attachment reactions of nitro aromatic explosives with thermal electrons. A thermal electron reactor is placed in tandem with electron capture detectors. Differential signal from the two detectors is used for monitoring explosive at trace levels. The sensor has been coupled with a rapid air-sampling device. The integrated system demonstrated detection limits down to sub parts per billion and a cycle time of 10 seconds with high selectivity. The system was tested at Sandia National Laboratories in June 2002. A human-portable system can be produced with useful sensitivities and a cycle time of five seconds.

2.10. New Radar System for Detection of Symmetrical Buried Objects [24-25]

The University of Kansas has developed a new radar configuration and processing strategy that allows discrimination of buried objects based on their forms of symmetry. The researchers demonstrated that a hand-held GPR can be constructed that can discriminate between symmetric and asymmetric buried objects. A system was built and subsequently tested at JUXOCO calibration lanes and demonstrated that a buried mine could be distinguished from a buried wooden asymmetrical object. A group theoretic description of bistatic scattering invariants for symmetric targets was developed verified with lab measurements. The team developed and demonstrated FDTD reverse time migration imaging algorithm using arrays of bistatic, near-field GPR measurements. They combined these results to develop and demonstrate a multi-resolution imaging technique that allows for both detection of subsurface objects and discrimination between landmines and clutter based on target geometric symmetry.

3. LISTING OF PUBLICATIONS

List of papers and reports submitted or published under ARO sponsorship during the reporting period (Jan. 20, 1997 - May 31, 2002), listed in the following categories:

3.1 Papers Published in Peer-Reviewed Journals

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14. R.J. Stanley, P. Gader, D. Ho, "Feature and Decision Level Sensor Fusion of Electromagnetic Induction and Ground Penetrating Radar Sensors for Landmine Detection with Hand-held Units", Information Fusion, 2002.

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15. P. Gader, B. Nelson, A. Hocaoglu, S. Auephanwiriyakul, and M. Khabou, "Neural versus Heuristic Development of Choquet Fuzzy Integral Fusion Algorithms for Land Mine Detection," chapter in *Neuro-fuzzy Pattern Recognition* H. Bunke, A. Kandel (eds.): World Scientific Publ. Co. pp. 205-226, 2000.

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5. REPORT OF INVENTIONS

Patents:

1. Buried Object Detection and Neutralization System, August 10, 1999 (W. C. Nunnally).

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